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USE OF PHASE TECHNIQUES FOR THE STUDY OF POLARIZATION PHENOMENA AT RADIOWAVE REFLECTION FROM METEOR TRAILS

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SUMMARY

The results are given of investigation by direct phase method of polarization phenomena at radiowave reflection from meteor trails. A method is proposed of polarization phenomenon indication during observations of drifts of meteor trails. The observed effect of resonance duration increase at passage to denser trails is evidence against the theory of "metallic" resonance.

If the magnetic field of the Earth is the cause of anisotropy in trails providing prolonged reflections, the trail's structure must be "looser" than that occurring in case of strictly ambipolar diffusion in the meteor trail.

* * *

A considerable attention is given to polarization phenomena in the works dealing with the theory of radiowave reflection from meteor trails [1 — 6]. The experimental investigations in that region concern, first of all, the measurements of correlations of meteor radioecho signal amplitudes. The observations of resonance phase shifts at coherent measurements [7] suffered from superimposition of diffraction and wind effects. Direct comparison of signal phases in crossed antennas with the help of phase technique has allowed us to separate the polarization phenomena

* ISPOL'ZOVANIYE FAZOVOY TEKHNIKI DLYA IZUCHENIYA POLYARIZATSIONNYKH YAVLENIY PRI OTRAZHENII RADIOVOLN OT METEORNYKH SLEDOV.

from those of diffraction and wind, and to observe the polarization phase shifts in all types of reflections, independently from their duration.

1. ORIENTATION OF A METEOR TRAIL RELATIVE TO ANTENNA SYSTEM

The expression, presented in reference [4] for electromotive forces (Emf) induced in crossed antennas, generalized to the case of arbitrary polarization of emitted signals, can be written in the form

$$E_x^* = K[E_x \cos^2\alpha + E_y \sin\alpha\cos\alpha + me^{i\varphi}(E_x \sin^2\alpha - E_y \sin\alpha\cos\alpha)]; \quad (1)$$

$$E_y^* = K[E_y \sin^2\alpha + E_x \sin\alpha\cos\alpha + me^{i\varphi}(E_y \cos^2\alpha - E_x \sin\alpha\cos\alpha)]. \quad (2)$$

where E_x and E_y are the radiated field components, α is the angle between the meteor trail and the axis x (the axes of coordinates being parallel to receiving antennas), m is amplitude ratio of the perpendicular and parallel components of the signal reflected from the meteor trail in the case when the corresponding incident wave components are equal, φ is the phase difference between the perpendicular and the parallel components of the signal on the condition that irradiation takes place in phase. It is assumed that the reflection point lies on the axis z of the coordinate system; K is a factor proportional to the reflection factor (generally speaking, K = K(t)).

At trail irradiation by linearly-polarized waves [4], the polarization ratio of signals, reflected from the meteor trail and induced in signals' crossed antennas will be

$$n = |E_x^*| / |E_y^*|. \quad (3)$$

the phase difference between E_x and E_y is

$$\Theta = \arg E_x^* - \arg E_y^*. \quad (4)$$

We plotted in Fig. 1 the graphs of n (t) and Θ (t) dependence at various α, according to formulas (3), (4) and the theoretical curves m (t) and φ(t), which are brought out in the Kaizer work [3] for resonance reflections.

At circular polarization incident upon the wave trail $E_y = E_x e^{i\pi/2}$. Correspondingly, the dependences n (t) and O (t) at various α, plotted with the aid of (2), (3) for the case $E_y = E_x e^{i\pi/2}$ and the theoretical curves by Kaizer [3] m(t) and φ(t), are shown in Fig. 2.

Therefore, depending upon the polarization of the transmitting antenna, the effect of meteor trail orientation relative to receiving vibrators is found to be essentially different and has to be taken into account when conducting polarization measurements.

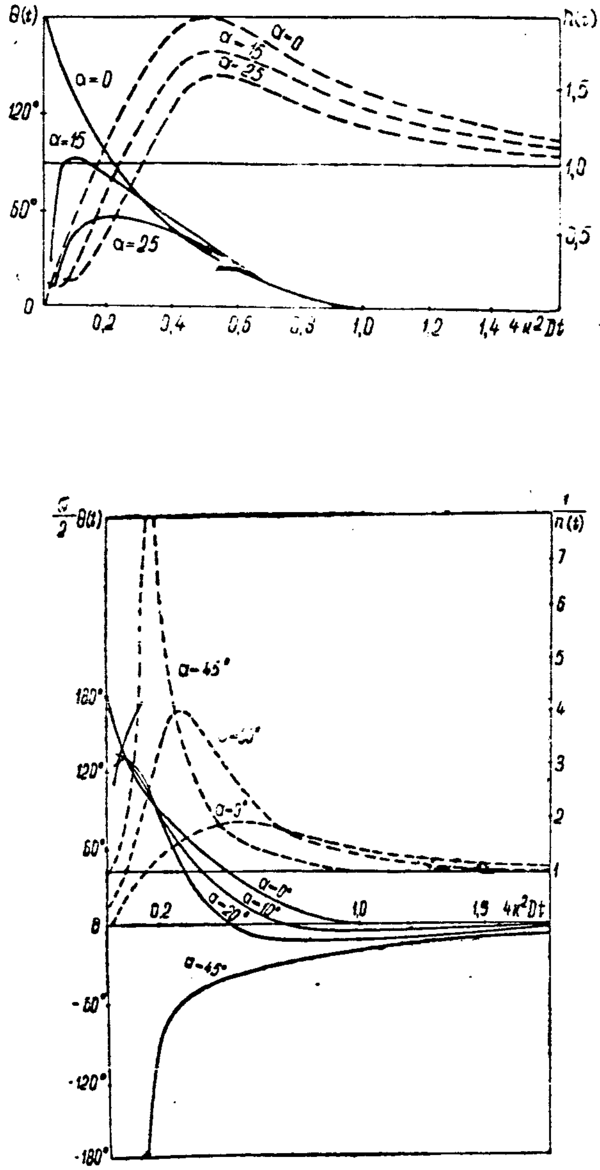

Fig. 2

The case, when the vector of polarization is parallel to one of the measuring antennas, will be considered below.

2. APPARATUS

Measurements were conducted at the meteoric station described in [8]. A transmitter of 120 kw in impulse power operated in the frequency of 33.5 mc/s on a feebly-directional antenna with circular polarization (two crossed loop-type vibrators)at 0.35 λ height above ground). Two identical receiving vibrators were switched to phasometric device input through antenna amplifiers. The received signals were registered by a photoindicator in the form of two vectors, one of which being the reference and the position of the second determining the phase correlation searched for. Besides, one of the measuring vector's coordinates was registered as a function of time and the distance to the meteor trail was also registered, alongside with the amplitude polarization ratio. An example of registration of resonance reflection for a transitional-type trail is shown in Fig. 3.

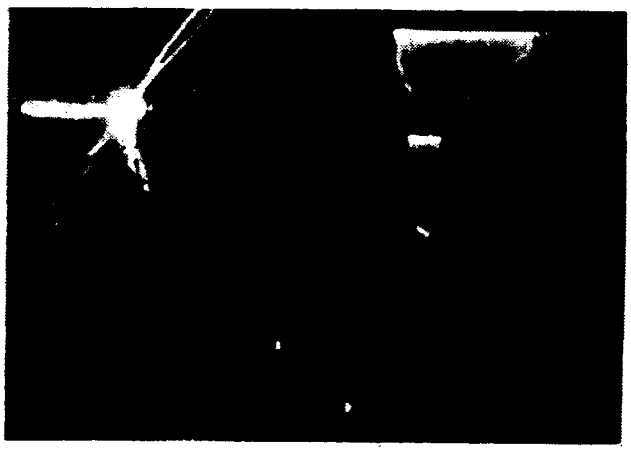

Fig. 3.

The data presented in the current work refer to observations carried out in June 1962. The experimental material includes mainly the sporadic meteors, though the period of observations was partly overlapping with the time of action of a weak meteor stream from the constellation Aries. Below, we shall mainly present a classification of the observations of the events and their comparison with the existing theories.

3. RESONANCE EFFECTS

From 2465 reflections registered during the observation time, 1069 failed to reveal any phase variation for the registration time and were classified as reflections from underdense trails. Of the remaining 1396 reflections, having revealed, one way or another, polarization properties, 720 were referred by the form of their time-amplitude characteristic to reflections from overdense trails. Here belong also the "nonspecular" reflections from overdense trails.

Inasmuch as, on the one hand, it is impossible to separate reliably the underdense trails from those only feebly overdense according to the form of the amplitude characteristic, and, on the other hand, judging the magnitudes of phase variations and the times of their manifestation according to theoretical predictions, there is no essential difference between plasma resonance in underdense trails and the resonance-type phenomena in a metallic cylinder, we did not take any special measure for careful separation of these two forms of resonance phenomena, sorting for analysis all the cases when the phase rotation can be observed at the initial stage of reflection. That is why a small number of reflections from feebly overdense trails were added to the 676 reflections sorted for analysis.

The maximum rotation angle of the measurement vector of the phasometer and the time, over which the process of phase settling ended, were estimated. The distribution of the observed magnitudes of phase variations is plotted in Fig. 4a. For the sake of comparison we plotted by dashes the results obtained in the work [7]. In our case the distribution maximum has been shifted by 20^{o} toward the side of small angles, while the maximum observable values are identical ($\simeq 120^{o}$). The possibilities of lowering our results of measurements are linked only with the presence of lag in the commencement of registration by a time of the order of 10 m sec; this, however, does not explain the observed discrepancy.

We plotted in Fig. 4б the time distribution from the beginning of echo to the times at which the phase variation ended, comparing them with the results of [7] (dashed histogram). (The latter were preliminarily summed up by 0.02 sec. intervals).

It may be seen from this diagram that the time scale of our distribution is stretched by about three times if we compare it to [7]. In order to estimate the contribution to this distribution that may be made by the nonrecognized feebly-overdense trails, we stressed the reflections with indices of overdensity by shading the respective parts of the histogram of Fig. 4 б).

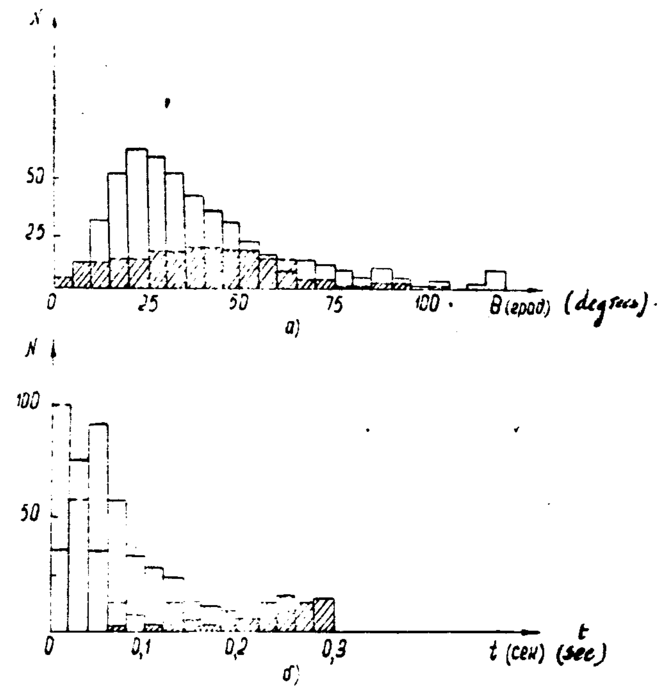

Fig. 4.

It was found, that the resonance duration increase is linked with the transition to denser trail. This result is in contradiction with the theoretical computation of [1], based upon the "metallic" model of an overdense trail, according to which the resonance time is curtailed as the electron density increases.

4. POLARIZATION MEASUREMENTS OF THE PHASE OF INDIVIDUAL REFLECTIONS

Examples of observed phase variations are brought out in Fig. 5. The instantaneous phase correlations were measured on a sliding scale with zero at the end of reflection, and brought out for every meteor with the x- and y- components of the amplitude of the reflected signal.

The first three examples a, б, в, are underdense trails with resonance. The extremes at the beginning of certain phase-time registrations are probably conditioned by trail axis rotation relative to antenna system

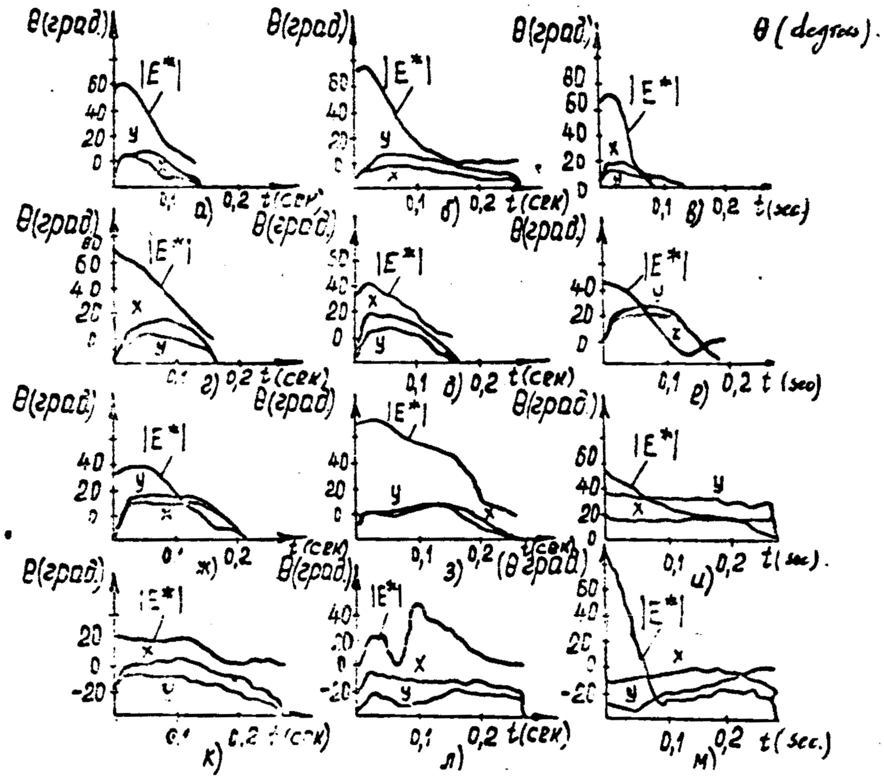

Fig. 5.

(see Fig. 2). The cases г and д may be referred to reflections from feebly-overdense trails (amplitude rise after the first maximum of the diffraction pattern); however, the character of phase difference variation in time remains as formerly, that is continuous rotation in the course of nearly the entire echo. The overdensity is still more strongly expressed in the case е, and especially in the case ж; however, the variation of phase is slowed down and it changes the direction only toward the end of reflection.

In the last case the resonance duration can no longer be explained from the viewpoint of resonance on a metallic cylinder. If we consider that the "metallic" resonance must cease when $(2\pi/\lambda)\, r_c = 1$ (r_c being the critical radius of the trail) [3], the resonance time is

$$\tau_p(h, \alpha) = \frac{r_t^{*2}(\alpha) - r_n^2(h)}{4D(h)} . \qquad (5)$$

Here r^*_t is the smallest of the two solutions of the equation for r_t (r_t being the diffusion radius and r_n the initial radius):

$$\frac{2\pi}{\lambda} r_t \left[\ln \frac{\alpha e^2}{\pi^2 m v^2 r_t^2} \right]^{1/2} = 1 \qquad (6)$$

(the expression for r_c is taken for the Gaussian distribution of electrons along the radius of the trail).

It follows from (6) that the maximum resonance duration is near 0.15 sec for the feebly-overdense echoes from the height of 80 km; (r_H (h) and D (h) were borrowed from [9]). For the case brought up in Fig. 5 б, $h \simeq 90$ km and $\alpha \simeq 4 \cdot 10^{12}$ electron·cm^{-1} and, consequently, the "metallic" resonance of such an echo must be "concealed" by the initial radius of the trail (note that the phase jump in Fig. 5k coincides with the period of destruction of the overdense trail).

The above-enumerated peculiarities in the behavior of the polarization correlation of phases for transitional trails are not unexpected. The incomprehensible behavior of the polarization correlation of amplitudes in transitional trails was already noted in the works [4, 6]. All the above-said allows to conclude that the theory of polarization phenomena in overdense trails, constructed in the assumption of "metallic" model of meteor trail, does not explain the observed phenomena, at least in the region of transitional trails.

For the completeness of the classification of the observed polarization phenomena we brought up in Figs. 5 л and к the typical examples of polarization fading, which is the result of trail axis rotation relative to antennas (see the cases of increase of polarization ratio in Fig. 2).

5. IDENTIFICATION OF POLARIZATION PHENOMENA DURING OBSERVATIONS OF METEOR TRAIL DRIFTS

The polarization phase rotations may overlap the drift rotations and entail errors in the measurement of wind velocity. If attention may be drawn to the sharp shortlived phase rotations by the disruption of regularity in the behavior of the phase-time characteristic, the smooth and durable polarization variations of phase can not, as a rule, be distinguished from the drift variations. To resolve the problem of effective detection of polarization phenomena at measurement of Doppler frequency shifts it is possible to make use of the links between the amplitude-temporal and the phase-temporal characteristics of reflections received on crossed vibrators.

Let us still consider a case, when the polarization vector of the transmitting antenna is parallel to one of the receiving vibrators. Assuming in (1) and (2) $E_y = 0$, we have

$$|E_x^*| = K[\cos^4\alpha + m^2 \sin^4\alpha + 2m\cos^2\alpha\sin^2\alpha\cos\varphi]^{1/2}; \qquad (7)$$

$$|E_y^*| = K\sin\alpha\cos\alpha[1 + m^2 - 2m\cos\varphi]^{1/2}. \qquad (8)$$

We plotted in Fig. 6a the graph of dependences $|E_x^*|K^{-1}$ and $|E_y^*|K^{-1}$ on time for various α; it may be seen from them, that the signal in the y-antenna appears only at time of resonance, when the reflected wave is polarized elliptically.

Let two identical independent receiving devices be switched to x- and y-antennas, of which one enters in the wind apparatus outfit. Assume that the signals from the amplitude detector of the main channel are fed ot X- , and from the complementary channel — to the Y-plates of the oscillographic indicator. These signals will deflect the ray of the oscillograph by an angle $\Psi(t) = \operatorname{arc\,cotg} n(t)$ to the axis x, which will vary with time correspondingly with the variation of the polarization correlation of phases, darkening of the film's certain sector with specific angular dimensions. The character of this variation is illustrated by the graphs in Fig. 6б , from which it follows, that the method here described has the greatest sensitivity at $\alpha = 45^o$ ($\Psi_{max} = 65^o$). However, even at $\alpha = 10^o$ and $\alpha = 80^o$, Ψ_{max} exceeds 15^o, which may be easily noticed.

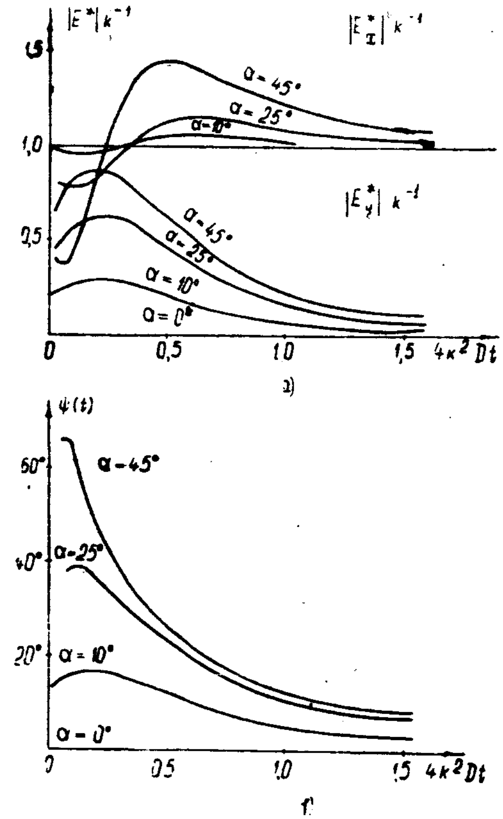

Fig. 6.

In the case when $\alpha = 0$ or $\alpha = \pi/2$, the polarization effects can no longer be revealed by that method; however, the danger is in fact present only for the case $\alpha = \pi/2$, for at $\alpha = 0$ only the "nonresonance" component of the field, parallel to the meteor trail, is responsible for the reflection. (See [1]). Considering that the proposed method is insentivitive in the region $\alpha = \pi/2 \pm \Delta\alpha_{min}$, where $\Delta\alpha_{min} \simeq 10^o$, we shall obtain for equally probable trail orientations a ninety percent (90%) probability that the polarization phenomena will be excluded. When using directional antennas with vertical polarization, the reliability of detection will increase, for, because of absence of trails parallel to horizon, the cases $\alpha = \pi/2$ are of little probability.

6. POLARIZATION PHENOMENA IN LASTING REFLECTIONS

For sufficiently large diameters of meteor trails the anisotropy linked with the difference in the curvature radii of the reflecting region decreases and, it seems that the polarization effects must vanish. However, the first observations have already shown that the overdense trails preserve their anisotropic properties during tens of seconds The character of phase difference fluctuations, beginning together with the fadings and lasting during the entire echo, point to substantial differences in polarization properties along the trail length.

63 reflections were sorted with duration of more than 2 seconds, that could be classified as specular. The phase variations were registered during 0.3 sec at 2 second intervals. The initial and final positions of the measurement vector were considered, in fact,as two independent readings. These were conducted from the value of phase difference at the beginning of echo.

We plotted in Fig. 7 the general distribution of the phase differences so registered. The distribution is asymmetrical : one-sign rotations prevail, though from the standpoint of possible orientations of the trails the x- and y- antennas are perfectly equal. This, apparently, is evidence that in lasting reflections the anisotropy is not conditioned by the orientation of the trail.

The distribution of the range of phase oscillations, linked with amplitude fluctuations (Fig. 7), shows that the difference in the polarization properties along the trail may reach 70° along phase. It was not possible to trace any sharp dependence between the phase and time fluctuations. In Fig. 8 a we brought out characteristic examples of average phase variation (during registration time) for 5 reflections,It may be seen from that figure that, alongside with cases of obvious rise in phase difference, there are observed examples of more complex behavior. A certain rise of the average phase difference, relative to the whole, can be seen as a function of time, in Fig. 8 б.

It is necessary to note that the above-enumerated polarization properties of prolonged reflections were obviously manifest in the experiments by Billam and Browne [4], who noted variations of the polarization ratio during deep fadings of the reflected signal. According to [4], turns up to 40° can be observed in the polarization planes at the expense of ionization in the D-layer when radar location of meteors is done. However, to explain the observed effects, it is necessary to assume that a phase difference of such, and higher order, must assure the fluctuations of electron density over a length of the order of 1 ÷ 5 km (characteristic distance between reflecting centers if the flvctuating meteor reflection). Moreover, the influence of ionized layers has a sharply expressed daily course ; however, the subdivision of the available experimental material into night and daytime did not permit to reveal any difference in the polarization properties.

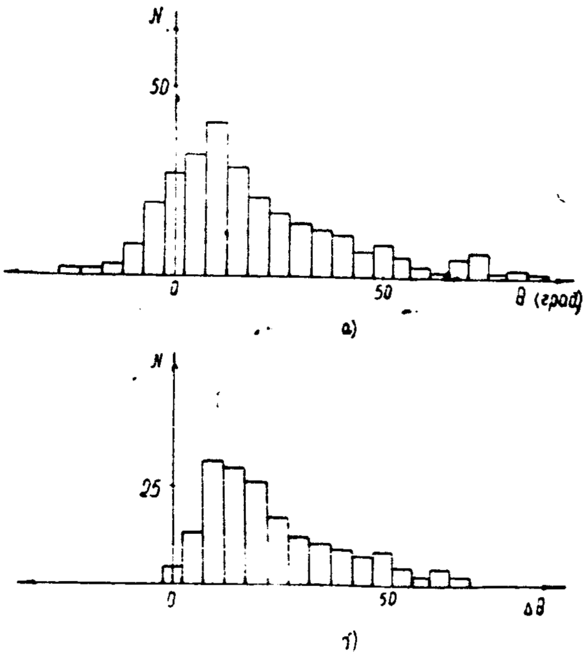

Fig. 7

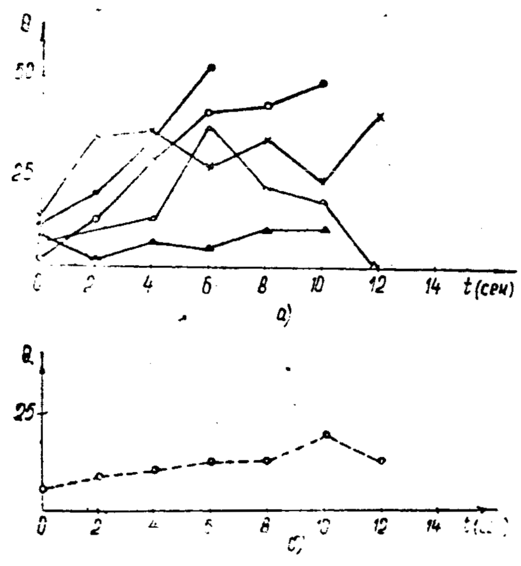

Fig. 8

The dual refraction in the external parts of the trail can be estimated from the standpoint of phase rotation by the correlation

$$\Theta = \frac{2\omega}{c}\int_{-\infty}^{r_c}\left\{(1-v_0)^{1/2}-\left[1-\frac{v_0^*(1-v_0^*)}{1-v_0^*-u_0^*}\right]^{1/2}\right\}dr. \qquad (9)$$

Here $v_0^* = v_0$, provided $v_0 \leqslant 1-u_0$, and $v_0^* = 1$, if $1-u_0 < v_0 < 1$; r is the current radius of the ionized trail; $_o$ is the ratio of the resonance frequency of the ionized plasma to the operational frequency; u_o is the ratio of the squares of electron gyrofrequency to operational frequency. It is assumed that the magnetic field vector is perpendicular to the propagation direction and coincides with the polarization vector of one of the receiving antennas. For the Gaussian distribution of electrons in the trail we have

$$v_0 = \frac{e^2\alpha}{m\pi^2\nu^2 r_t^2}\, e^{-(r/r_t)^2} \qquad (10)$$

where α is the linear density of electrons, ν is the operational frequency $r_t^2 = r_H^2 + 4\,Dt$, D being the diffusion coefficient.

Conducting the numerical integration of (9) for $\alpha = 10^{14}$ el·cm^{-1}, $\nu = 33.5$ mc/s, $D = 6 \cdot 10^4$ cm^2·sec^{-1}, $h \simeq 95 \div 100$ km, we shall obtain that 4.5 seconds after the beginning of reflection Θ may attain 5.7°. This is nearly by one order less than the values measured by us.

Therefore, the results of the experiments, presented above, can only agree with the hypothesis of magnetic rotation on the basis of a substantially looser or more friable model of overdense trail than was assumed in [1]. It is possible that in order to explain the observed effects we may have to involve again the turbulent diffusion [11], or else, consider from that viewpoint the inhomogenous "flares" of weak ultraviolet ionization along the trail. In any case, the asymmetry of the distribution in Fig. 7a and a certain increase of polarization effects with time compel us to seek the cause of anisotropy in the effect of the Earth's magnetic field.

***** THE END *****

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